UAVSAR Real-Time Embedded GPU Processor

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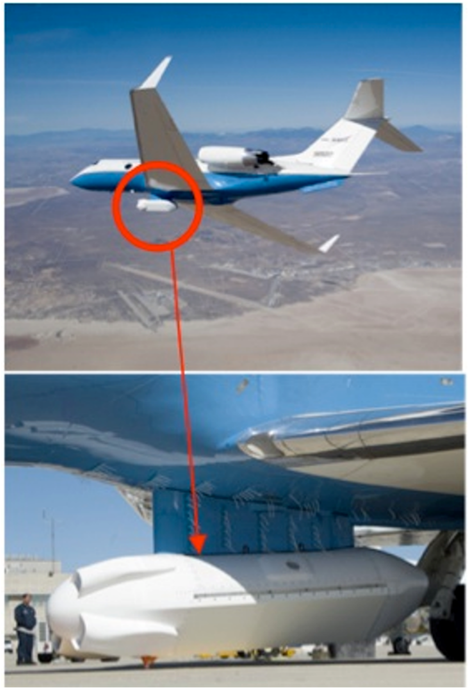
Introduction

- Background & Motivation
- Hardware
- Algorithms
- Results

Background & Motivation

Frequency band	L-band [1]	Ka-band [2]
Frequency (GHz)	1.2575	35.66
Nominal bandwidth (MHz)	80	80
Nominal slant range resolution (m)	1.8	1.8
Azimuth resolution (m)	0.8	0.3
Polarization	Quad-pol	HH
Nominal altitude (km)	12.5	12.5
Pulse length (μs)	5-50	5-50
Peak transmit power (W)	3100	80
Nominal spatial posting (m)	6	3
Nominal range swath (km)	22	11
Look angle range	25 - 65°	10 - 50°



[1] Fore *et al.*, "UAVSAR Polarimetric Calibration," in IEEE TGRS, vol. 53, no. 6, pp. 3481-3491, June 2015.
[2] Hensley *et al.*, "Ka-Band Mapping and Measurements of Interferometric Penetration of the Greenland Ice Sheets by the GLISTIN Radar," in IEEE JSTARS

Background & Motivation

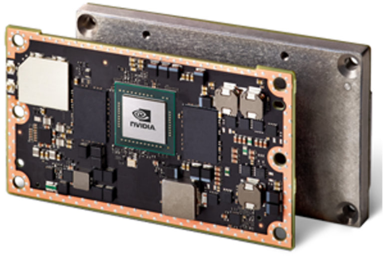
- Original OBP based on Xilinx Virtex 5 FPGA [1]
  - Fixed point arithmetic, implemented in VHDL
  - Range-Doppler algorithm with RCMC and MoCo
  - Partial swath
- UAVSAR digital system upgrade
  - 10 Gbps Ethernet interface for raw data

[1] Lou *et al.*, "Onboard Radar Processor Development for Rapid Response to Natural Hazards," in IEEE JSTARS,

Hardware

- NVIDIA Tegra development kits

Device	CPU cores	GPU cores	Memory	Power
TX2	4+2	256	8 GB	< 10 W
Xavier	8	512	16 GB	~10 W



Hardware

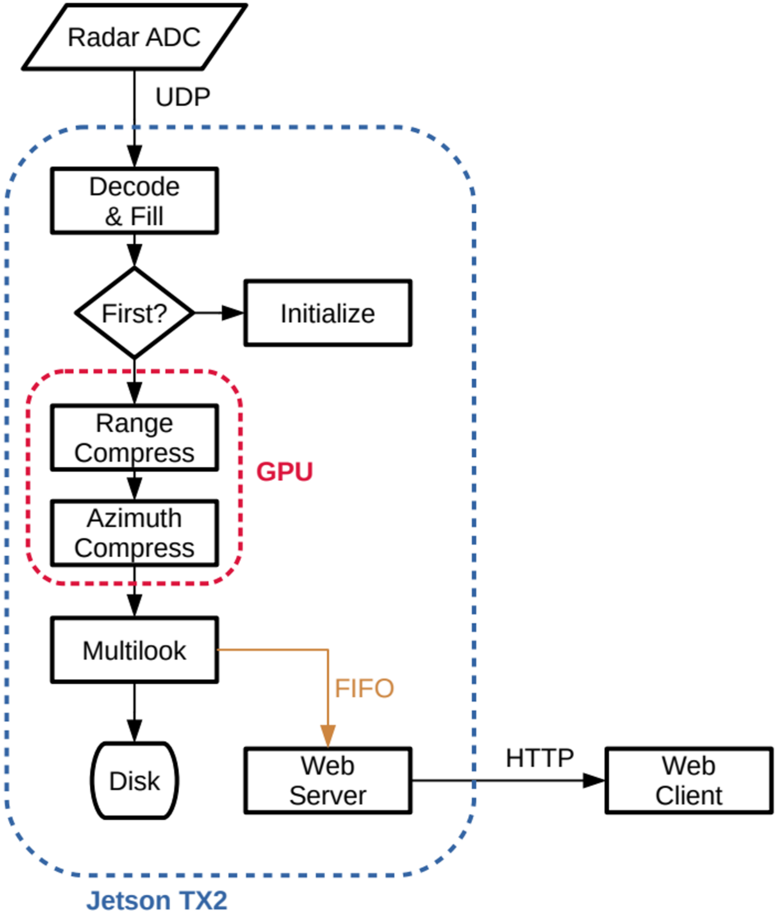
- Spaceflight GPU hardware becoming available

- GPU radiation fault tolerance is under research

[1] Rech *et al.*, "An Efficient and Experimentally Tuned Software-Based Hardening Strategy for Matrix Multiplication on GPUs," in IEEE Trans. N
[2] A. Milluzzi, A. George and A. George, "Exploration of TMR fault masking with persistent threads on Tegra GPU SoCs," 2017 IEEE Aerospace
[3] Powell *et al.*, “Commercial Off-The-Shelf GPU Qualification for Space Applications,” NTRS 20180006906, Sept. 2018.

Algorithms

- Range compression
  - FFT convolution
- Azimuth compression (L) or “Unfocused” (Ka)
- Geolocation

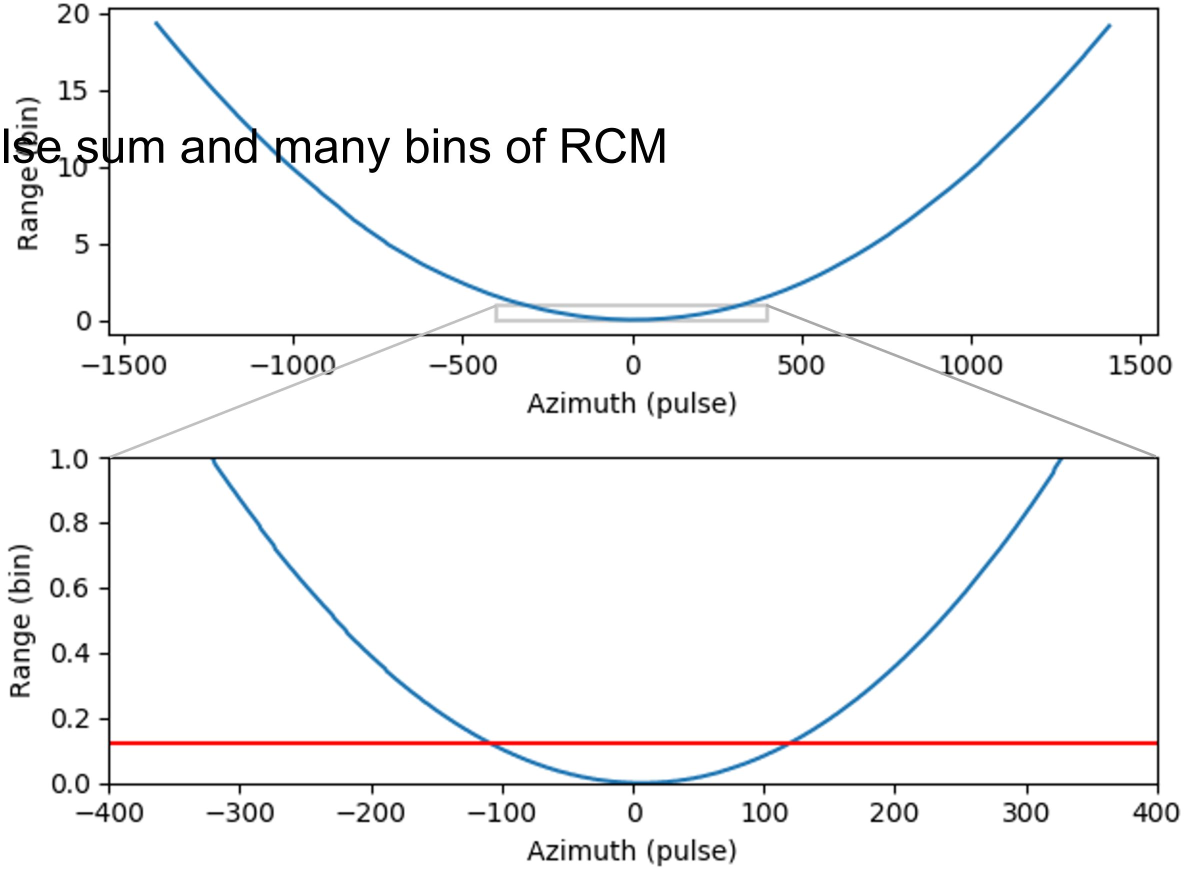


Algorithms: Azimuth Compression

- Low-resolution Range-Doppler
- Use short blocks so we can
  - Neglect range cell migration correction
  - Assume motion errors are mostly linear
- Take advantage of UAVSAR Doppler steering

Azimuth Compression: Sizing

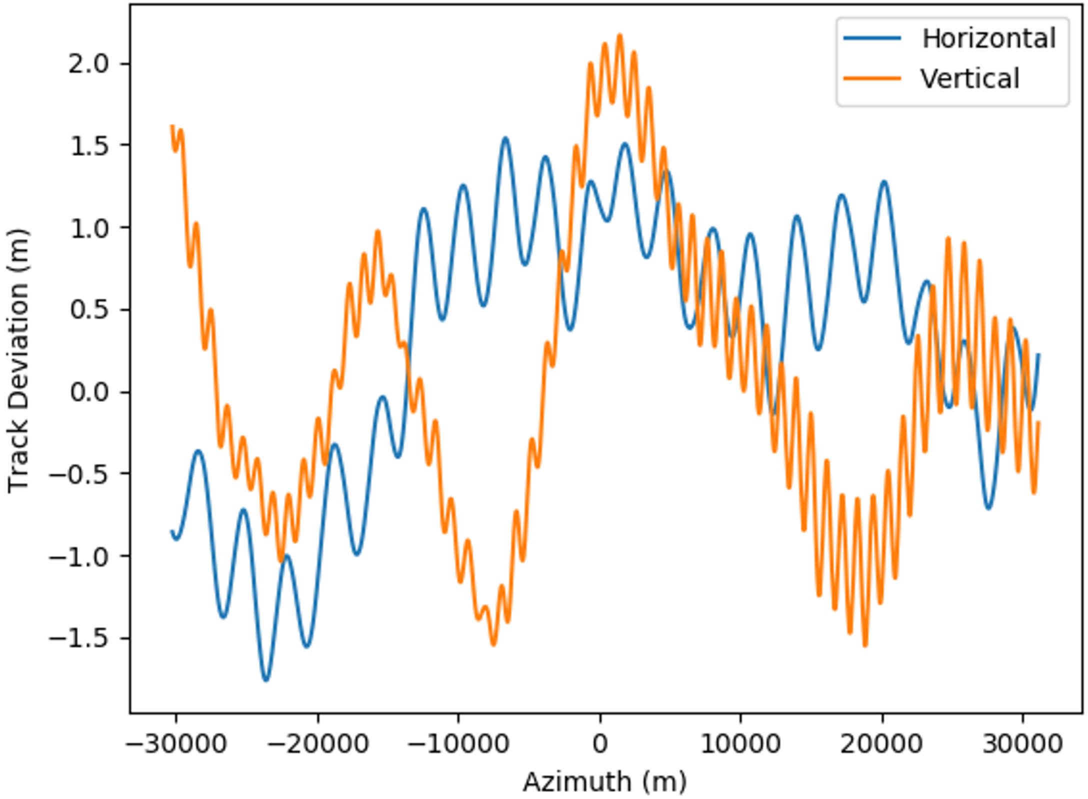
Full resolution requires 3000 pulse sum and many bins of RCM



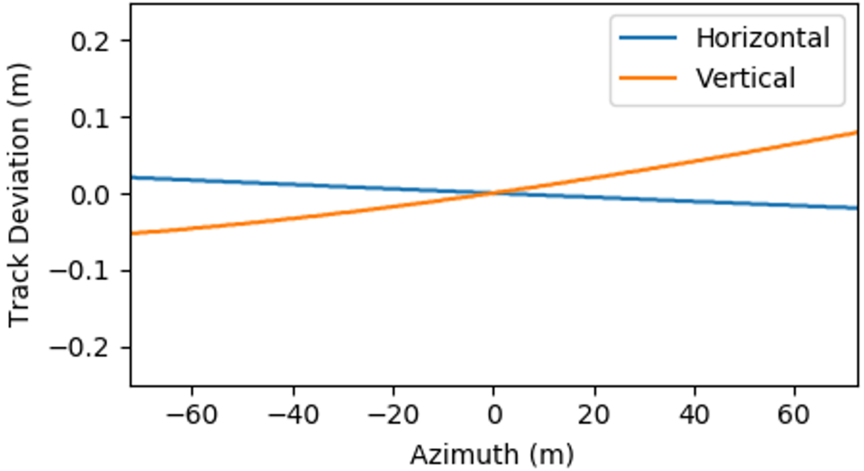
Limit aperture so that
RCM < ΔR/8
N≈256
δs≈10 m

$$\delta s \approx \frac{0.886\lambda R}{2N\Delta s}$$

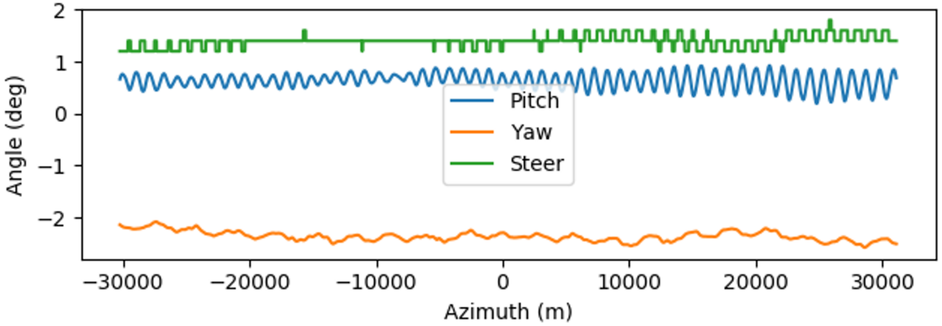
Azimuth Compression: Sizing

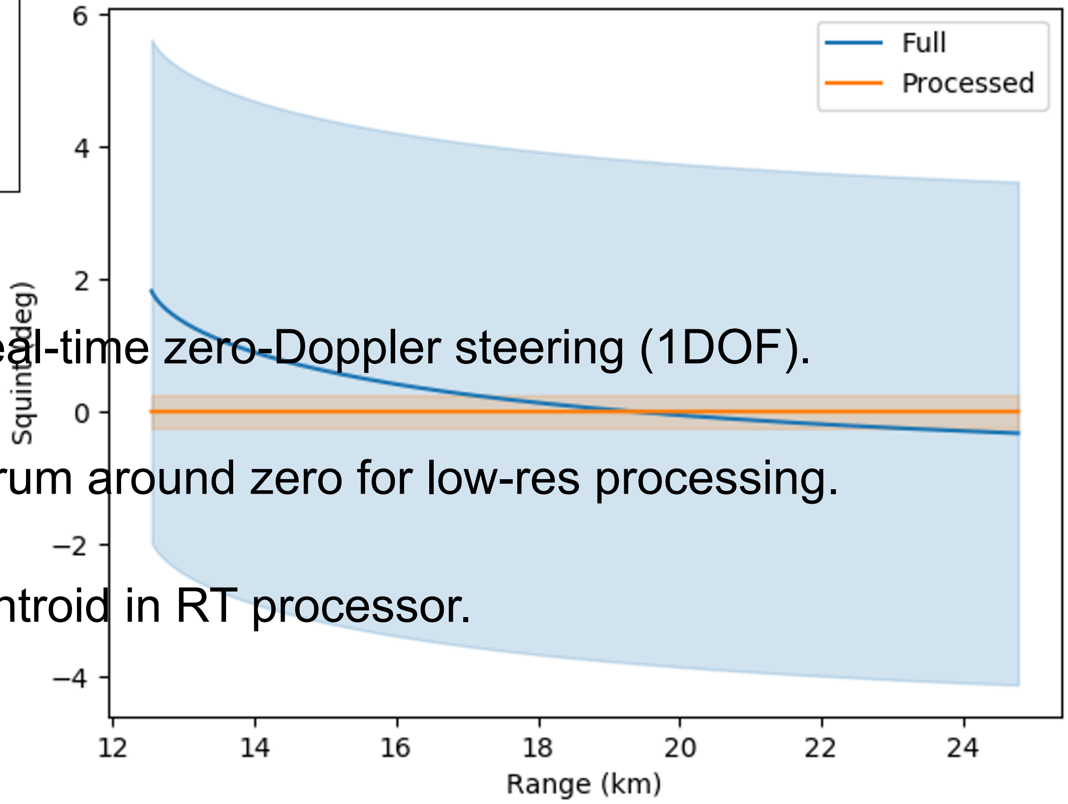


At short apertures, the platform motio



Azimuth Compression: Doppler

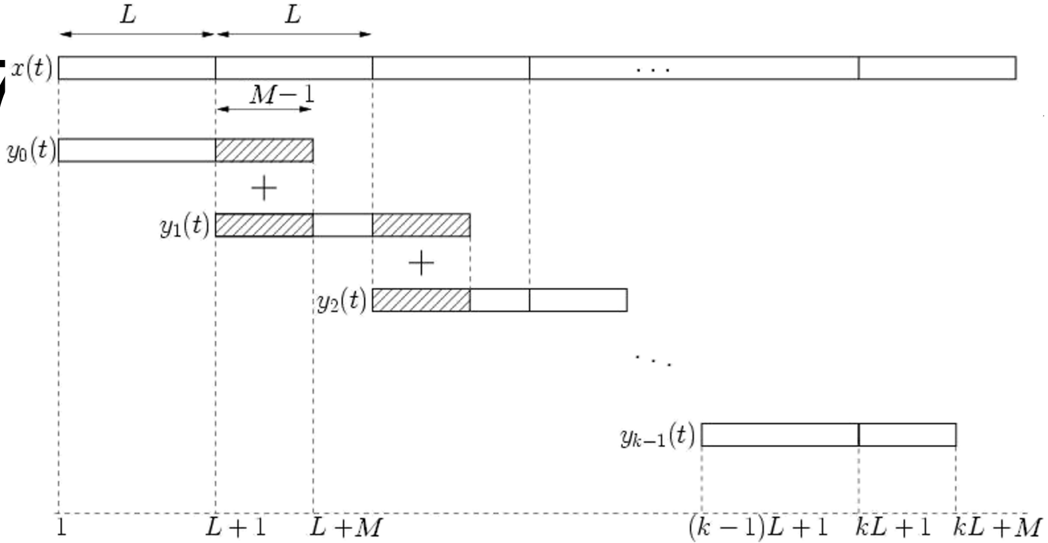




- UAVSAR has active array antenna with real-time zero-Doppler steering (1DOF).
- Can always count on at least some spectrum around zero for low-res processing.
- No need to compute/estimate Doppler centroid in RT processor.

Azimuth Compression

- Doppler=0 & no motion compensation
  - Can use fixed azimuth reference function.
- Compute and FFT azref. in setup step
- Focus in 7 overlap-
add convo



Unfocused InSAR

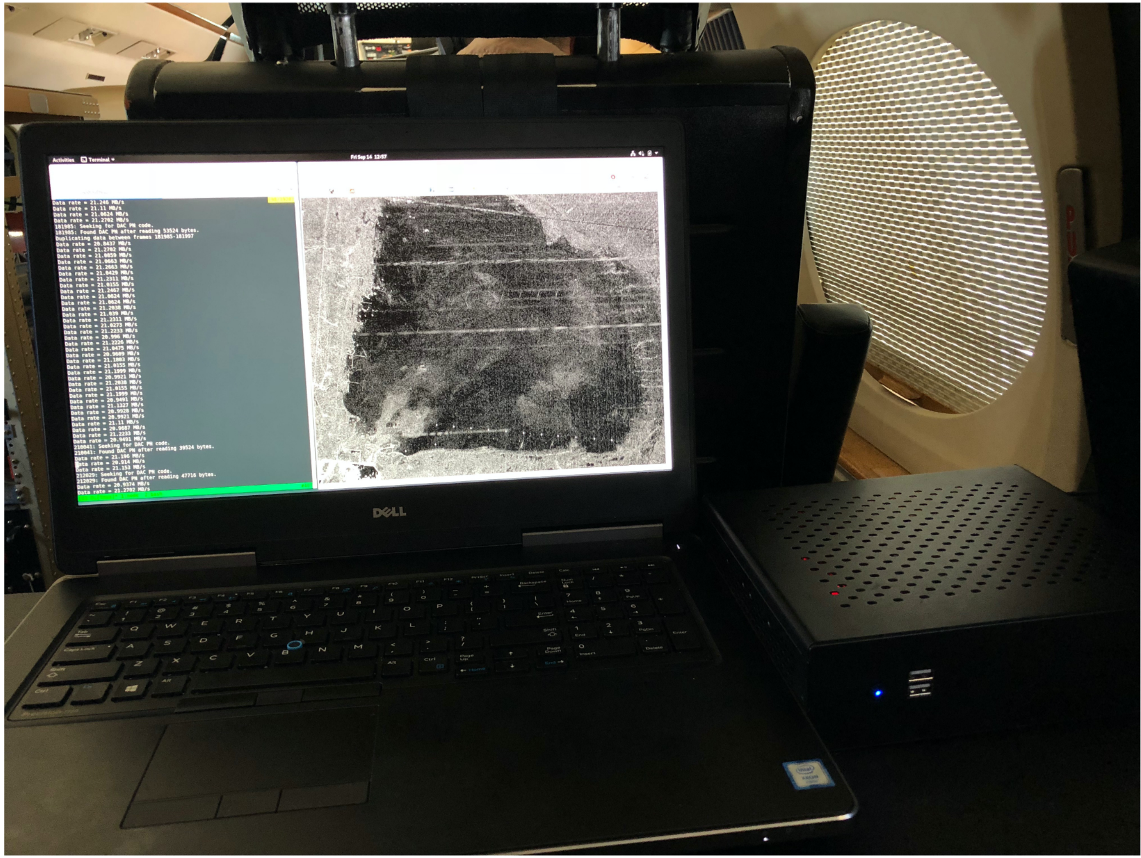
- Ka-band interferometer does not have Doppler steering, but have same carrier on both channels
- Interfere range-compressed data directly and sum over short azimuth blocks to obtain interferogram.

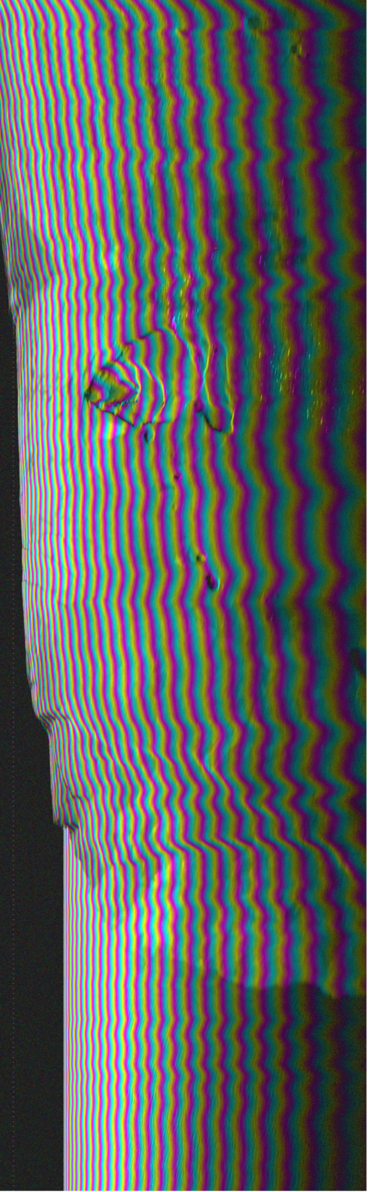
Software Implementation

- Standard Linux OS on 64-bit ARM, use systemd to manage daemons.
- No need for real-time OS or explicit synchronization.
- Range compression and azimuth compression implemented in **CUDA** and use cuFFT library
  - Roughly 300 lines of CUDA code.
  - GPU and CPU use same physical memory

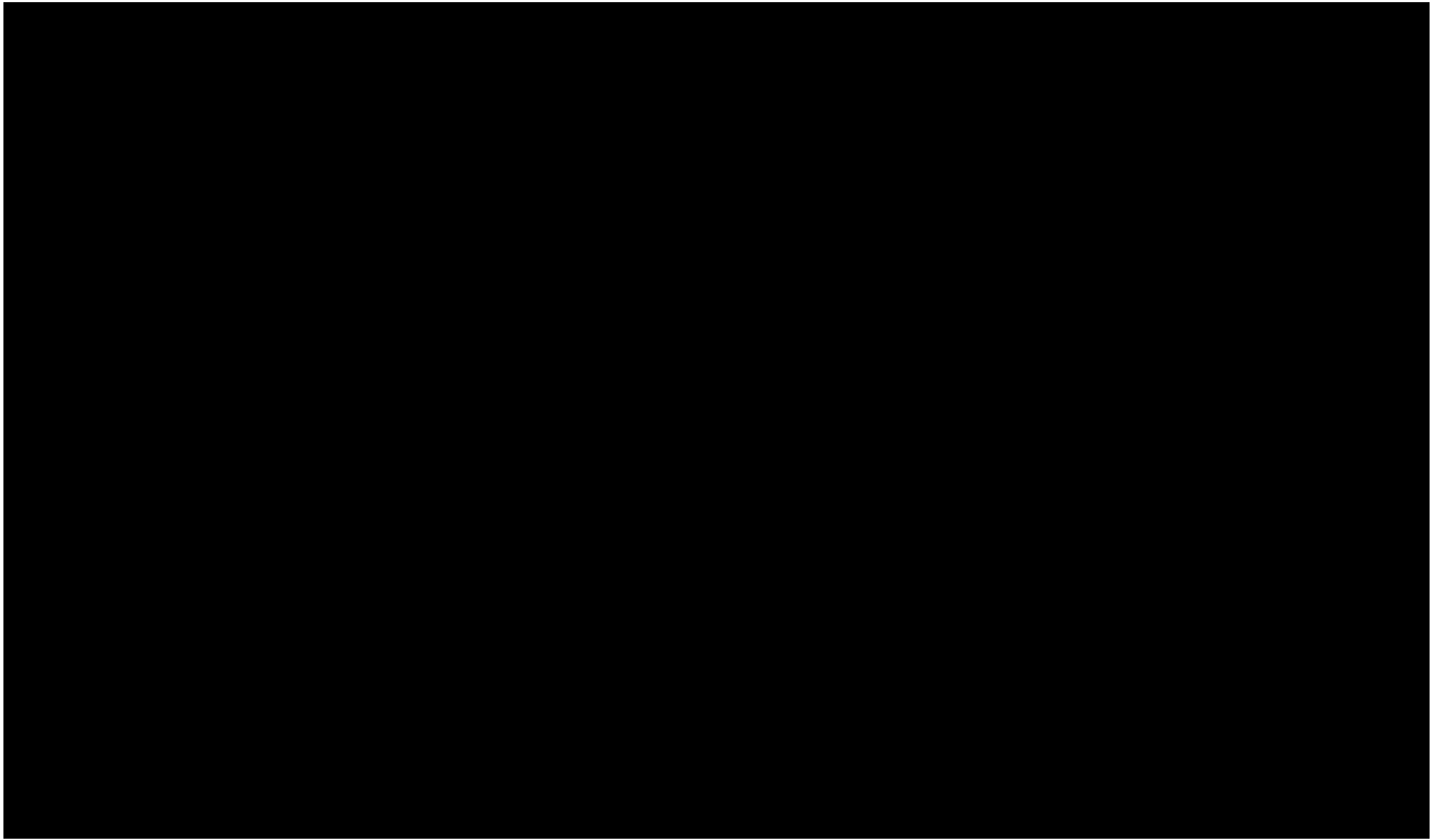
Results

- Simple animated web interface.
- Anyone on aircraft network can access processor URL and view image stream in browser.



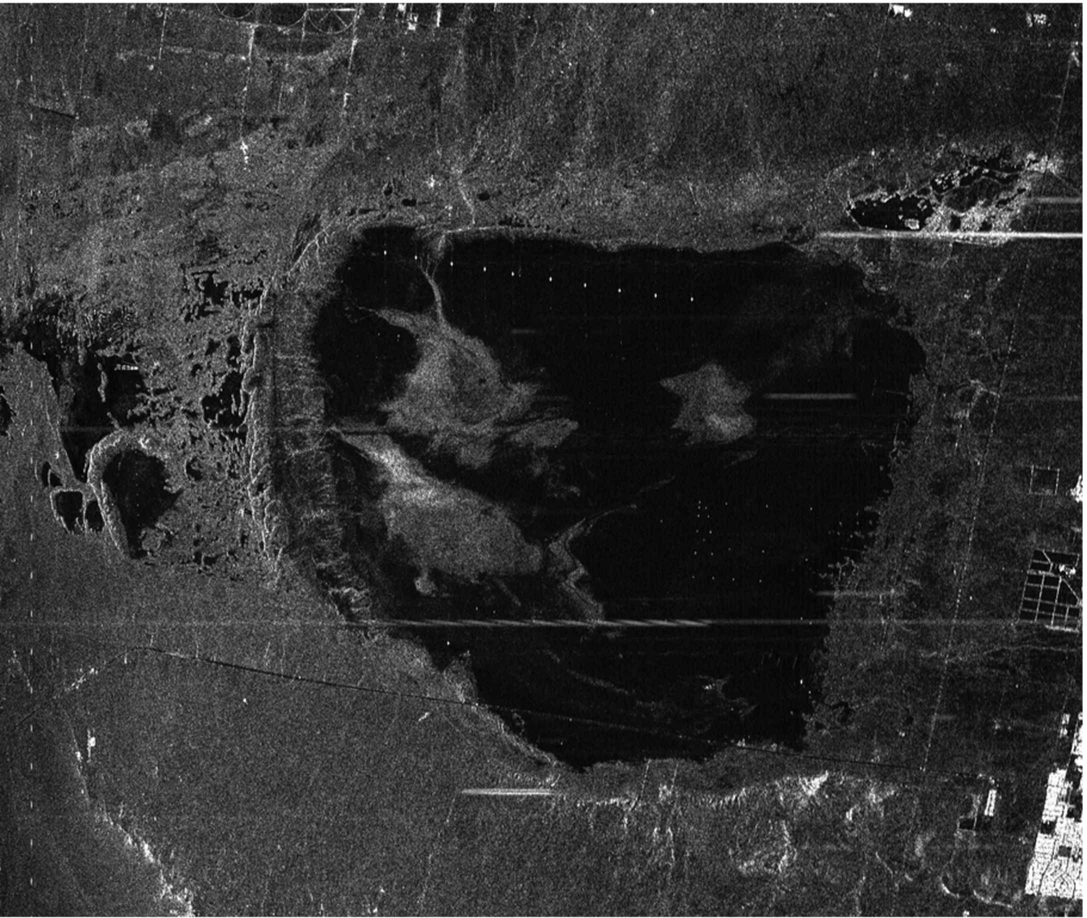


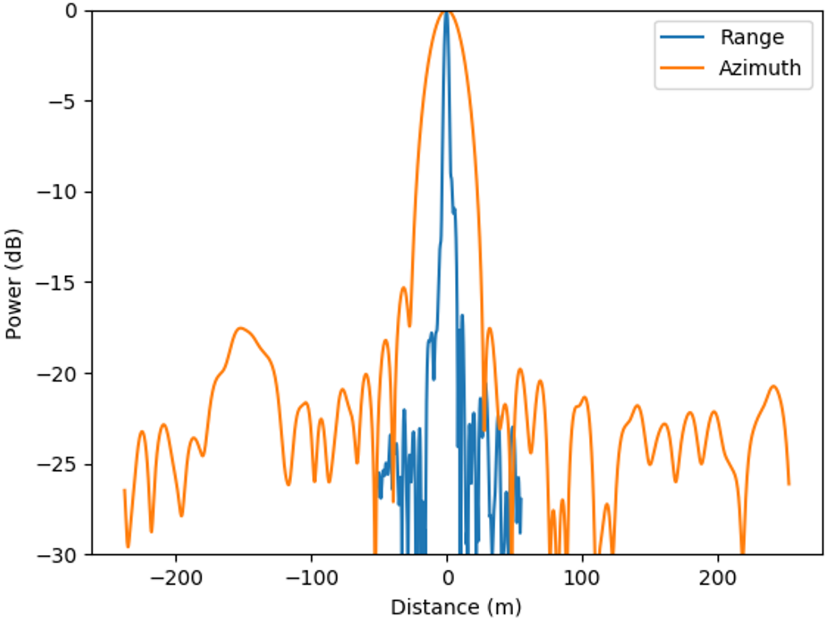
Results: Ka-band



Results

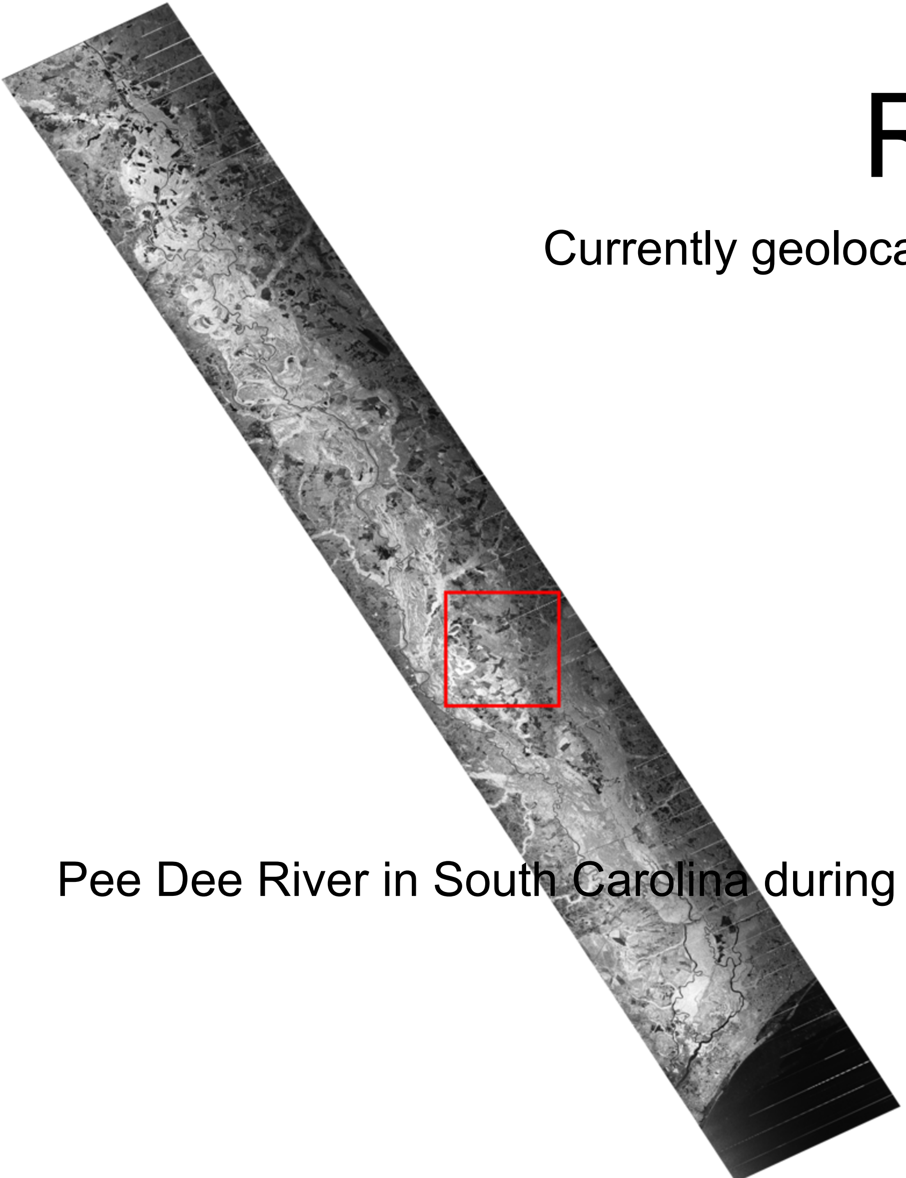
Rosamond Corner Reflector Array

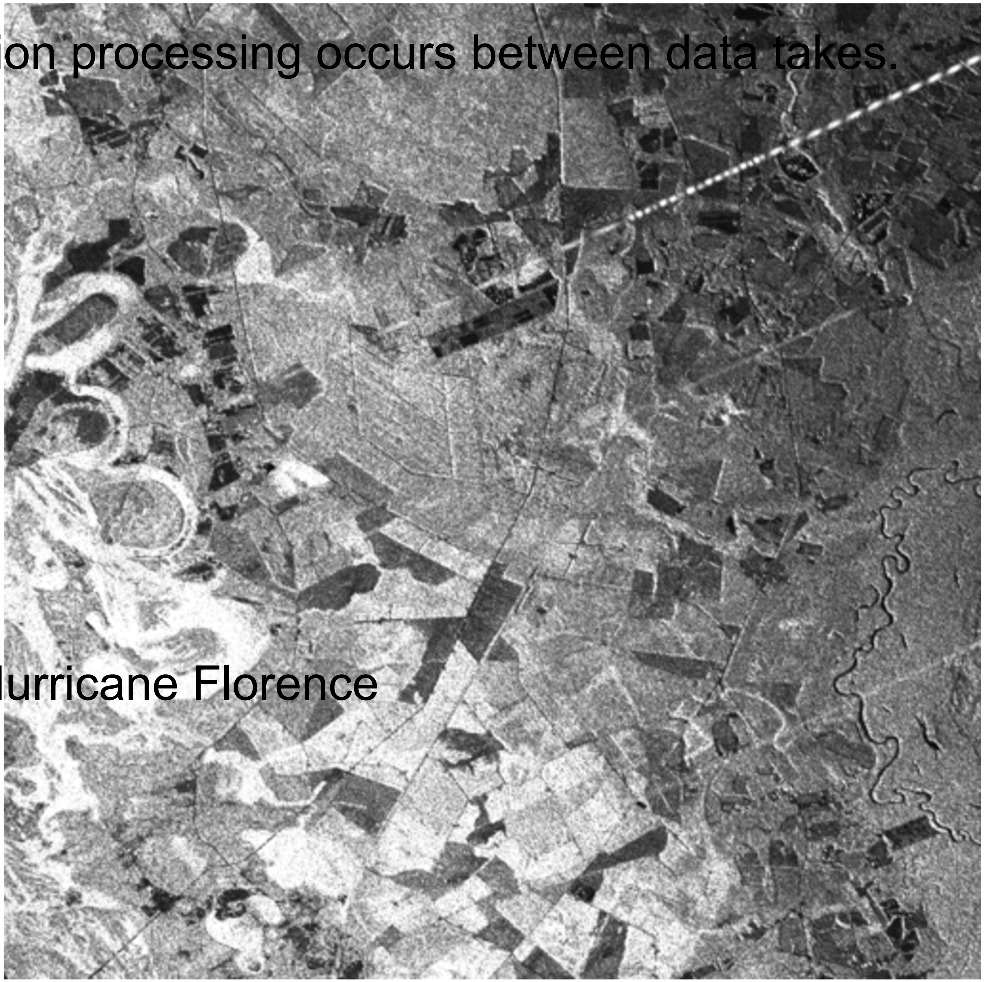




Results

Currently geolocation processing occurs between data takes.





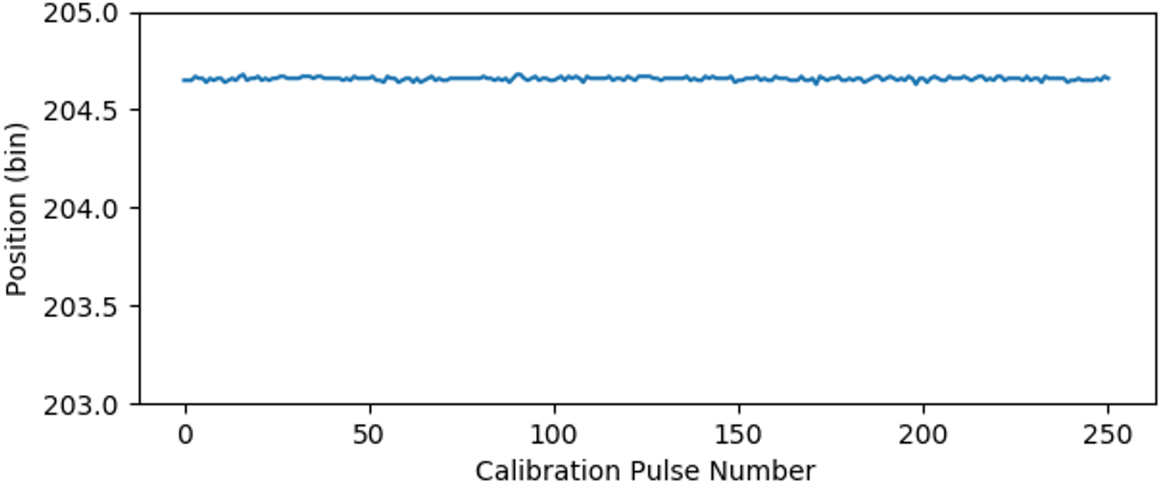
Pee Dee River in South Carolina during Hurricane Florence

Results

- Under 50% compute resource utilization according to gtop
- Roughly 7.5W power draw for entire box (TX2) during operation.

Results

- Implemented basic analysis of internal calibration signals.
  - Allows radar operator to detect certain kinds of digital anomalies and take corrective action.



Future Work

- Need real-time position solution for motion compensation.
  - Low-latency Kalman filter blend of GPS+INU data.
  - Prerequisite to higher fidelity processing.
- Improved azimuth compression algorithm.
  - Could handle bulk moco+RCM with little added computation.